# Enhancement of Charm Quark Production Due to Nonlinear Corrections to the DGLAP Equations

K.J. Eskola[1,2], V.J. Kolhinen[1] and R. Vogt[1,3,4]

[1] *Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40014 Jyväskylä, Finland*
[2] *Helsinki Institute of Physics, P.O. Box 64, FIN-00014 University of Helsinki, Finland*
[3] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA*
[4] *Department of Physics, University of California, Davis, CA*

Global fits of parton distribution functions (PDFs) have been obtained by several groups. These PDFs, based on DGLAP scale evolution, fit the deep inelastic scattering (DIS) HERA data on the proton structure function $F_2(x,Q^2)$ at large scales, $Q^2 \geq 10$ GeV$^2$, and momentum fractions $x \geq 0.005$ very well. However, at small scales, $Q^2 \leq 4$ GeV$^2$, and at small momentum fractions, $x \leq 0.005$, these fits are not as good. In this region, the gluon recombination terms, giving rise to nonlinear corrections to the evolution equations, become important. The first of these nonlinear GLRMQ terms were included in the leading order (LO) DGLAP evolution equations. The HERA DIS $F_2(x,Q^2)$ data are reproduced with these EHKQS PDFs, obtained in Ref. [1], employing LO-DGLAP+GLRMQ evolution.

Introducing the GLRMQ terms slows the scale evolution. At $Q^2 \leq 10$ GeV$^2$ and $x \leq 0.01$, where the nonlinearities are important, the gluon distributions are larger than in pure DGLAP. The enhancement, large at small scales, vanishes as the nonlinear terms become negligible at larger scales. At $Q^2 \geq 10$ GeV$^2$, the evolution is dominated by the DGLAP terms. The HERA data suggests a factor of $\sim 3$ gluon enhancement at $x \sim 10^{-4}$ and $Q^2 = 1.4$ GeV$^2$.

Here, we discuss how charm quark production in $pp$ collisions could probe this enhancement [2]. Charm production is an ideal choice since the charm mass is low and its production is dominated by gluons. Assuming factorization, inclusive differential charm cross sections at high energies is

$$d\sigma_{pp}(\sqrt{s}) = \sum_{i,j=q,\overline{q},g} f_i(x_1,Q^2) \otimes f_j(x_2,Q^2) \otimes d\hat{\sigma}_{ij}(Q^2,x_1,x_2) \quad (1)$$

where $\hat{\sigma}_{ij}(Q^2,x_1,x_2)$ are the perturbative partonic cross sections for charm production at scales $Q^2 \gg \Lambda^2_{\rm QCD}$, $x_i$ is the parton momentum fraction and $f_i(x,Q^2)$ are the free proton PDFs. We assume that the renormalization and factorization scales are equal. Only the $gg$ and $q\overline{q}$ channels enter at LO.

We calculate the ratio of differential cross sections,

$$R(p_T,y,y_2) \equiv \frac{d^3\sigma({\rm EHKQS})/(dp_T dy dy_2)}{d^3\sigma({\rm CTEQ61L})/(dp_T dy dy_2)}, \quad (2)$$

where $p_T$ is the charm quark transverse momentum and $y$ and $y_2$ are the rapidities of the charm quark and the antiquark. The results for the enhancement are plotted in Fig. 1 as a function of $p_T$ for fixed $y$ and $y_2$. The largest enhancement is obtained at the largest $\sqrt{s}$ where the $x$ values are smallest. We use $m_c = 1.2$ GeV and $Q^2 = 4m_T^2$ (left-hand side) and $m_c = 1.3$ GeV, $Q^2 = m_T^2$ (right-hand side). Both choices lie within the applicability region of the PDFs. For the highest energy, 14 TeV, the enhancement at $p_T \sim 0$ is a factor of $\sim 5$ for $m_c = 1.3$ GeV and $\sim 1.5$ for $m_c = 1.2$ GeV. We repeated the calculations for larger masses, up to $m_c = 1.8$ GeV for both $Q^2 = m_T^2$ and $Q^2 = 4m_T^2$ and found smaller enhancements, $\sim 2$ and $\sim 1.25$ at $p_T \sim 0$, respectively. The charm enhancement can be substantial, but it is very sensitive to $m_c$ and $Q^2$. It also vanishes rapidly with $p_T$.

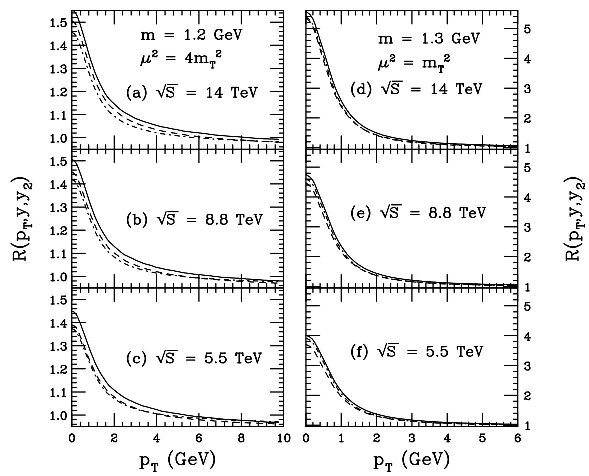


FIG. 1: The ratio of differential charm cross sections, $R(p_T,y,y_2)$, for $y = y_2 = 0$ (solid), $y = 2$, $y_2 = 0$ (dashed) and $y = y_2 = 2$ (dot-dashed) as a function of $p_T$ at $\sqrt{s} = 14$ (top) 8.8 (middle) and 5.5 TeV (bottom) in $pp$ collisions.

Since the DGLAP gluon distributions are already well constrained by the HERA data, they cannot absorb additional large effects. We conclude that, if this small-$p_T$ enhancement in the charm cross section relative to the DGLAP-based result is observed in the future experiments e.g. at the LHC, it is a signal of nonlinear effects on the PDF evolution.

[1] K. J. Eskola, H. Honkanen, V. J. Kolhinen, J. w. Qiu, and C. A. Salgado, Nucl. Phys. **B660**, 211 (2003).
[2] K. J. Eskola, V. J. Kolhinen, and R. Vogt, Phys. Lett. **B582**, 157 (2004).